

PRELIMINARY STUDY OF THE RELATION BETWEEN THERMAL EMISSIVITY AND PLANT TEMPERATURES.*

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Whenever a plant leaf is exposed to radiant energy from a source such as the sun this energy has three modes of dissipation: (1) reflection from the surface of the leaf, (2) absorption by the leaf, (3) transmission by the leaf. The quantitative value of the first varies with the nature of the receiving surface and the wavelength of the incident radiation. The value of the second varies with the nature and thickness of the absorbing tissue and the wavelength and intensity of the radiation. The amount of energy transmitted depends upon the wavelength of the radiation, the transparency and diathermancy of the leaf tissue. Of the three named possibilities of energy dispersal the second only is capable of raising the temperature of the leaf tissue and is the subject of investigation in these experiments.

In general, the leaf tissue will absorb solar energy of the period to excite the molecular vibration within the tissue concerned. The energy absorbed is mostly in the form of longer waves many of which are in the visible spectrum. These waves suffer a degradation of energy content and are emitted from the tissue as waves of a lower refrangibility.

The energy absorbed by a leaf may be dissipated in the following ways:

1. Thermal emission (radiation and conduction to the air).
 2. Conduction to internal tissue of lower temperature.
 3. Transpiration.
 4. Photochemical reactions (photosynthesis and others).
- Respiration, an exothermic reaction, is also taking place and needs to be evaluated.

RELATIVE IMPORTANCE OF DISPERSAL METHODS.

Investigations have shown the thermal unimportance of respiration and photosynthesis in considering plant temperatures. Miller (5) in a review of the literature, says the values for the percent of incident radiation used in photosynthesis range from .5% to 7.7%. However, the more recent experi-

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ments, Miller (6); Putter, as quoted by Spoehr (9); and Transeau (10) place the amount at less than 4%. The latter has calculated his results for corn on the basis of the total available energy per acre over a 100-day growing season in the vicinity of central Illinois. He also found that of the total available energy, only .5% was returned to the environment by respiration. Brown and Escombe (1) say that a respiring *Liriodendron tulipifera* leaf comes into thermal equilibrium with its surroundings at .019° C. In the following experiments the thermal exchanges of respiration and photochemical reactions have been neglected as insignificant.

The dissipation of heat energy by conduction to internal tissue of lower temperature has no significance in the cases where the substance is partially diathermanous or is sufficiently thin to become practically uniformly heated throughout. The latter is the case in all of the following experiments.

The poor thermal conductivity of succulent tissue may be significant in the prevention of killing by heat or frost of desert cacti which are exposed for a few hours to extreme temperature conditions. Such may be the case in the larger succulents such as *Carnegiea gigantea* under conditions of intense insolation. Conduction through tissue of high specific heat and low diathermancy must be responsible for part of the cooling of the surface. A rather steep gradient of temperature is probably maintained between the internal and external tissues.

Transpiration has long been considered one of the most important methods of energy dispersal by the leaf tissue. Brown and Escombe (1) working with *Helianthus annuus*, concluded that transpiration accounted for 80% of dispersal of available energy and therefore considered this process very important as a means of energy dissipation. Shull* (8)

*Shull gives figures part of which were taken from the work of Brown and Escombe, in which the incident radiation is .8 cal. per sq. cm. per min.; the coefficient of absorption is 65%; the mass beneath a sq. cm. of leaf surface is .02 gms. and the specific heat is .879. With these figures, and assuming no energy dispersal he calculates the rate of temperature rise of the leaf to be 29.6 degrees per min. But Brown and Escombe also say that a moderate rate of thermal emission is .014 cal. per min. per sq. cm. of leaf surface for each degree temperature difference.

Using these figures we see:

$$\frac{.8 \times .65}{2 \times .014} = 18.5 \text{ C.}^{\circ}$$

Thus the leaf would come into thermal equilibrium with its environment at a temperature 18.5 C.° above the environment and the rate of temperature rise equal to 29.6 C.° per min. holds at no time except when there is no temperature difference between the leaf and the air.

said, "There is no doubt that transpiration is vitally necessary, and that its chief function is energy dispersal."

Clum (3) has performed an exhaustive series of experiments to determine the cooling power of transpiration. As a result of his investigations, he concludes, "The review of the literature shows that the temperature of plant tissues is usually higher than that of the air in bright sunlight, but is subject to wide and rapid fluctuations. From the available evidence, however, the cooling effect of transpiration seldom exceeds 2 or 3 C. degrees."

Miller and Saunders (7) made over one thousand determinations of leaf temperatures of soy beans, corn, sorghum, cowpeas and alfalfa growing under field conditions in Kansas. They found no significant difference between air and leaf temperatures. They also found that the temperature of wilted leaves above that of turgid leaves in sunlight varied from 2 to 6 C. degrees.

As a result of these and other similar investigations, showing that at best transpiration could account for only a few degrees of cooling in leaf tissue, and since the range of temperature differences used varied from 3 to 30 C. °, the temperature effects of transpiration have been neglected in these experiments.

McDougal (4) using a clinical thermometer thrust into the tissue of a prickly pear cactus found that it attained a temperature of 31° F. above air temperature, that elongation continued even at 137° F., and that heating to 144° F. would not permanently injure the plant.

Clum (3) found that the presence of a large water content seemed to make little difference in the rapidity of temperature fluctuations, noting that the fresh leaf fluctuated as rapidly and over as wide range as the dried one. My own results do not agree with this as I found small but consistently greater emissivity values for dried leaves than for fresh ones of higher water content.

Brown and Wilson (2) have investigated the effects of thermal emission on plant temperatures. Proceeding on the assumption that a leaf maintained at a temperature above that of the surrounding air will lose heat at the same rate that a leaf maintained the same number of degrees below air temperature will gain heat, they were enabled, by the differential transpiration method to determine the rate of emission in terms of calories per unit of surface and time, and for a

one-degree temperature difference between the leaf and its surroundings.

Although these investigations involved a range of only two degrees, from 17° to 19° C., these authors conclude that, "The variation of the coefficient of emissivity with temperature can safely be neglected for any range of temperature to which the leaf may be subjected under natural conditions." The experiment was carried on with similar leaves from four different species and the results agreed very closely.

Clum (3), however, agrees with other investigators, that the leaf temperatures calculated from the emissivity formula of Brown and Wilson are consistently below those temperatures which have been observed by means of the thermocouple. The reason for this may lie in the method of determining leaf temperatures which Brown and Wilson used. The temperatures they recorded with their platinum resistance thermometers in contact with the leaf surface could at best record only the temperature of that surface and actually must have been somewhat influenced by the higher temperature of the surrounding air.

Even though the differential method was used, the thermometer which was at a lower temperature would be more influenced by the higher air temperature. Thus the heat which flowed into the plant per degree temperature difference was calculated to be greater than it probably actually was, with a consequent too great value for the emissivity factor.

Clum also notes that, "... the temperature of the leaf is so influenced by the intensity of the light that one can tell very little about the transpiration rate from the temperature and emissivity as calculated for leaves in the dark." That this is a legitimate criticism can be seen at once by noting the absurdity of the result obtained under certain conditions by the use of the formula which Brown and Wilson (2) proposed, viz.,

$$E = Qh/(\theta - \theta')$$

where E is emissivity, Q is grams of water lost, h is the latent heat of vaporization of water, and $(\theta - \theta')$ is the temperature difference between the leaf and air. One can readily conceive of a case where the radiant energy absorbed by a leaf would be just sufficient to carry on transpiration. Thus the temperature difference would be zero and emissivity would take on an infinite value.

APPARATUS.

The thermocouple set-up consisted of a mirror galvanometer used in conjunction with two junctions of copper and constantin wire. B&S Gauge 30 constantin wire and B&S Gauge 40 copper wire were soldered to form each junction. The constantin was introduced through a glass tube which had been drawn out to capillary size and then broken off back just far enough to permit a rather snug fit of the wire. This wire was allowed to protrude about two centimeters from the end of the glass capillary and copper wire was soldered to the constantin. The glass tube was carefully advanced upon the constantin until it just touched the soldered portion of the junction, the copper wire remaining on the outside. A piece of B&S Gauge 22 copper wire of sufficient length to reach a single pole switch was soldered to the No. 40 copper about five centimeters from the junction.

Another piece of tubing whose internal diameter was sufficient to hold the original tubing and the No. 22 copper wire was also drawn out to a fine capillary. This tube was then placed over the junction, enclosing the smaller tube, all of the No. 40 copper and about two centimeters of the end of the No. 22 copper wire. These were held firmly in position within the tube by means of sealing wax having a high melting point. None of the wax, however, was permitted to come into contact with the junction. The external tube was broken off so that both tubes ended at the junction, which was allowed to protrude about 1 mm. beyond the end of the glass. Construction of the couple with this fine wire permitted a junction to be used whose size caused a minimum of injury to the tissue into which it was inserted.

The galvanometer was the Leeds and Northrup type 2285-X.

As most of the thermal measurements were to be between 20° and 50° C., it was desired to have the reference junction somewhere within this range, and a method of keeping it at constant temperature. This was accomplished by allowing water to come into equilibrium with a 37.5° C. incubator. This water was then poured into a thermos bottle which had also been in the incubator for several hours and sealed with a single hole rubber stopper through which the reference junction, similar in construction to the one described above, was placed. This junction then remained within the incubator during the

course of the experiments. The actual temperature of this junction was determined by a zero galvanometer reading. The thermocouple was then calibrated, using a large standardized mercury thermometer graduated to 0.1° C. so that one cm. on the galvanometer scale corresponded to approximately one degree. Temperatures accurate to 0.1° C. could easily be read.

The heating element used in some of the experiments was the Rodale Straight Type Heating Element, similar to that used in many reflecting heaters. An ordinary metal reflecting lamp shade was placed around the element.

EXPERIMENTAL PROCEDURE.

According to definition, emissivity is the rate of thermal emission, or the number of calories lost per unit of time from a square centimeter of surface of a body for each degree of temperature difference between the body and its surroundings. In order then to know the corresponding temperatures to which the body will be subjected, it is necessary to know the mass, specific heat, and area of surface of that body.

The following experiments are, however, based upon rates of temperature loss, and the rate of cooling is expressed in terms of degrees lost per minute for each degree difference in temperature. A determination of rates of temperature loss provides a more significant as well as more accurate means of making comparison between leaf tissues from different plant species. It has the added experimental advantage that determinations can be made upon the tissue concerned while attached to the plant.

On all the plants the rate of thermal emission was calculated by observing the temperatures at equal intervals of time of a plant leaf which was cooling to room temperature, or rising from room temperature as a result of being placed in a constant temperature oven or exposed to radiation from the heating element. The results agree quite closely showing that absorption and emission are practically the same for any given temperature difference.

The rate of temperature loss for any temperature was found as follows: The leaf was heated by means of incident radiation from the heater element. The latter was mounted on the top of a revolving stool so that it could quickly be removed from the region of the plant by a half revolution of the stool top.

When the desired temperature difference was attained the

heater was removed and the leaf began to drop in temperature. Readings on the galvanometer were taken at 10-second intervals until the leaf had come into thermal equilibrium with its environment. The average temperature for two successive readings was found and subtracted from the equilibrium temperature. This was called the average temperature difference. The difference between successive readings gave the temperature drop during that 10-second interval. When multiplied by 6, this gave the rate of temperature loss per minute for the average temperature difference already determined.

A graph was then constructed using the average temperature differences as abscissae and the rates of temperature loss as ordinates. A comparison of the curves of a number of leaves of the same type, i. e., of the same species and maturity, from different plants not only showed very close agreement in rates of temperature loss, but above a temperature difference of 3 C.°, the curve was practically a straight line.

A straight line was then fitted to these data by the method of least squares. The result was a linear equation of the form

$$d\theta_t/dt = K\theta_t + b$$

where $d\theta_t/dt$ is the rate of temperature loss at time t , and θ_t is the temperature difference at time t . Since we know the rate of cooling must be zero when there is no temperature difference the value of 'b' is at once fixed at zero.

Therefore, the rate of cooling for any temperature difference above 3 C.° is proportional to the temperature difference multiplied by a constant 'K' which varies with the nature of the tissue.

DERIVATION OF THE GENERAL COOLING LAW.

It is desirable to investigate the general law of cooling which these tissues were found to follow.

Let θ_t be the temperature difference t seconds after leaf begins to cool.

Let $d\theta_t/dt$ be the rate of temperature loss at time t .

Let K be the constant whose value we seek.

Then the law of cooling is

$$d\theta_t/dt = -K\theta_t$$

or

$$\int d\theta_t/\theta_t = -K \int dt$$

whence

$$\log_e \theta_t = -Kt + \log_e c$$

where e is the base of the natural logarithms and $\log_e c$ is the constant of integration.

Then

$$\theta_t = c e^{-Kt}$$

We know that for 't' equal to zero

$$\theta_0 = c$$

The constant 'c' is therefore determined to be numerically equal to the initial temperature difference, θ_0 .

The rate of cooling after any time t has elapsed can be found by substituting the number of minutes for t in the following formula.

$$R_t = d\theta_t/dt = -\theta_0 K e^{-Kt}$$

A comparison of cooling rates after any time interval t , for the same or different leaf tissues can then be made even if the initial temperature differences be not the same. In such a case the constant θ_0 is made to correspond to the initial temperature differences for the respective tissues.

It remains then, to determine 'K' for tissues of varying degrees of succulence and water content.

DETERMINATION OF 'K' FOR FRESH LIRIODENDRON LEAVES.

Liriodendron tulipifera seedlings, three years of age, were transplanted from the garden into the greenhouse. They ranged in height from $1\frac{1}{2}$ to 4 feet. Only mature leaves were used in the experiments. The junction of the couple was inserted into the mesophyll near the midrib. The insertion was placed on the under side of the leaf and care was taken to prevent its penetration into the upper epidermis upon which the radiation from the heating element was received.

The following series of experiments was performed. A different attached and mature leaf was used in each experiment. Leaves from three trees were used. Fourteen experiments were made in all.

1. Heated with element to 36° and allowed to cool to 22° C.
2. Heated with element to 35° and allowed to cool to 21° C.
3. Heated with element to 43° and allowed to cool to 24° C.
4. Heated with element to 29° and allowed to cool to 21° C.
5. Heated with element to 33° and allowed to cool to 22° C.
6. The heater was turned upon a leaf at about room temperature and the leaf was allowed to heat until the galvanometer showed an approximately uniform rate of rise. Readings at ten second intervals were then taken.

- a. Heating from 33° to 44° C.
- b. Heating from 31° to 38° C.

From these data the average value of 'K' and the probable error of the mean were found to be

$$K = 2.1 \pm .11$$

The equation of cooling for *Liriodendron tulipiera* is

$$d\theta_t/dt = -2.1 \theta_t$$

and the temperature difference after any number of minutes 't' is

$$\theta_t = \theta_0 e^{-2.1t}$$

where ' θ_0 ' is the initial temperature difference between the leaf and the air.

DETERMINATION OF 'K' FOR MESEMBRYANTHEMUM.

The plant used was *Mesembryanthemum crystallinum*. The leaves were in a turgid healthy condition. The thermocouple junction was inserted into the mesophyll so that radiation from the heater was allowed to fall upon the leaf on the side opposite that in which the insertion was made.

In these experiments the leaves were heated to about 40° C. and allowed to cool to equilibrium at 22° C. Temperature readings were taken each ten seconds during the cooling period. Four experiments were made. A different leaf from the same plant was used in each experiment. The average value of 'K' and the probable error of the mean are:

$$K = .45 \pm .02$$

The equation of cooling for *Mesembryanthemum* is

$$d\theta_t/dt = -.45 \theta_t$$

and the temperature difference after any number of minutes 't' is

$$\theta_t = \theta_0 e^{-.45t}$$

where ' θ_0 ' is the initial temperature difference between the leaf and air.

DETERMINATION OF 'K' FOR BYROPHYLLUM CALYCINUM.

The *Bryophyllum calycinum* leaves used were from plants which had reached maturity in the greenhouse. Four types of experiments were made, each with a different leaf.

1. Heated in incubator to 54° C. and allowed to cool to 24° C. in air. These leaves were detached from the plant.

2. Heated by heater element to 42° C. and allowed to cool to 24° C. The leaves were attached to the plant.

3. Detached leaf at 23° C. was placed in a 58° C. incubator and the rate of temperature rise of the leaf was taken at ten second intervals.

4. Attached leaf heated by element until uniform rate of rise was observed on the galvanometer. Initial recorded temperature 29° C., final temperature 45° C.

Eight experiments were made. The results of these were averaged and 'K' for fresh *Bryophyllum calycinum* was calculated from the formula. The average value of 'K' and the probable error of the mean were found to be

$$K = .38 \pm .02$$

The equation of cooling for *Bryophyllum calycinum* is

$$d\theta_t/dt = -.38 \theta_t$$

and the temperature difference after any number of minutes 't' is

$$\theta_t = \theta_o e^{-.38t}$$

where ' θ_o ' is the initial temperature difference between the leaf and air.

DETERMINATION OF 'K' FOR ECHEVERIA WEINBERGIA.

In these experiments mature and turgid leaves of *Echeveria weinbergia* were used. The junction was inserted into the mesophyll so that it lay about midway between the epidermal tissues. The leaf was heated to 48° C. by means of the heater element and allowed to cool to equilibrium temperature. Temperature readings were taken each ten seconds during the period of cooling. Six experiments were made, each with a different leaf on the same plant. The value of 'K' and the probable error of the mean were then calculated to be

$$K = .08 \pm .004$$

The equation of cooling for *Echeveria weinbergia* is

$$d\theta_t/dt = -.08 \theta_t$$

and the temperature difference after any number of minutes 't' is

$$\theta_t = \theta_o e^{-.08t}$$

where ' θ_o ' is the initial temperature difference between the leaf and air.

DETERMINATION OF 'K' FOR CEREUS.

The *Cereus* used was a four-ribbed rooted cutting, six inches high, which appeared in healthy condition. The thermocouple was inserted into the stem until the junction lay about midway between the epidermal tissues. The plant and junction were placed in the incubator whose temperature was 55° C., and the temperatures were recorded at intervals of one minute until equilibrium was reached. The plant was then taken from the incubator and allowed to cool in air and temperature readings were again taken each minute. From the series of eight experiments, four of the heating and four of the cooling type, the value of 'K' and the probable error of the mean were computed to be

$$K = .05 \pm .002$$

The equation of cooling for *Cereus* is

$$d\theta_t/dt = -.05 \theta_t$$

and the temperature difference after any number of minutes 't' is

$$\theta_t = \theta_0 e^{-.05t}$$

where ' θ_0 ' is the initial temperature difference between the stem and air.

EFFECT OF DESICCATION ON THE CONSTANT 'K.'

Having obtained the value of 'K' for several normal tissues, the effect of drying out on the rate of thermal emission could be put upon a quantitative basis.

Accordingly the following experiments were performed with *Liriodendron* and *Bryophyllum* leaves.

The junction was inserted into a leaf of *Liriodendron tulipifera* attached to the plant. Radiation from the heater element was then thrown upon the upper surface until a temperature of equilibrium at 40° C. was reached. The leaf was subjected to this temperature for one hour. At the end of this time several brown spots had appeared and the margin had begun to curl slightly. The heater was removed and temperatures of cooling were recorded at ten second intervals. Four experiments were made. The average value of 'K' was computed and found to be 2.5. This is about 19% above the value found for fresh leaves of the same species.

A leaf of *Bryophyllum calycinum*, attached to the plant, was heated by the heater element to 50° C. and maintained at that temperature for 90 minutes. One experiment was made. 'K' was calculated to be .45. This value is 18% greater than for the fresh leaf.

Another leaf of *Bryophyllum calycinum* was detached from the plant and suspended within a constant temperature oven at 55° C. for 26 hours. It was then removed and the temperature record of cooling was kept as before. Two experiments were made. The value of 'K' in this case was found to be .69. This is 80% above the value found for fresh leaves of the same species.

TEMPERATURE EFFECTS OF RESPIRATION AFTER INJURY.

Since injury to a tissue sometimes results in increased respiration it was desired to find the temperature effects of this increase caused by insertions of the thermocouple.

Three leaves of *Bryophyllum calycinum* each of which had been punctured in several places with the thermocouple were suspended near the top of a quart size thermos bottle. The thermocouple was inserted into the mesophyll of the second leaf. The bottle was filled with water at room temperature within three or four centimeters of the leaves and was then closed with a rubber stopper. This was done to saturate the atmosphere in which the leaves were suspended and thereby reduce heat losses by transpiration.

At the end of twenty minutes, no temperature change was noted. The temperature then began to rise slowly and at the end of four hours had reached a maximum of 1.3 C.° above air temperature.

However, of the experiments performed to determine the values of 'K,' none lasted more than one hour and twenty minutes, only one insertion of the thermocouple was made and there was no confinement permitting the accumulation of heat.

Thus, it is seen that under conditions which were more favorable to show temperature effects of respiration after injury than those obtaining during the determination of 'K,' no significant thermal effects were noted. The increased temperature effects of such respiration have therefore been neglected as insignificant.

EFFECT OF VASELINE UPON THERMAL EMISSIVITY.

Leaves of *Liriodendron tulipifera* and *Bryophyllum calycinum* were coated with a thin layer of vaseline over both surfaces and a redetermination of 'K' was made. In *Liriodendron* the layer of vaseline caused an 18% drop in the emissivity constant, while the constant for *Bryophyllum* was reduced by 13%.

In order to find the magnitude of the effect due to vaseline alone it was necessary to apply it to a plant tissue having a minimum of water loss. Therefore, the four ribbed cutting of *Cereus*, whose emissivity constant 'K' had already been determined to be .05 was entirely coated with vaseline and the value of 'K' again found. A decrease of 11% was noted.

Since the water losses in *Cereus* over the period of the experiment (one hour and twenty minutes) were insignificant, the 11% decrease in the value of 'K' must be due to the presence of the vaseline itself. If this be true, then complete prevention of transpiration causes a 2% drop in emissivity in *Bryophyllum* and 7% in *Liriodendron*. Thus the small portion of the value of 'K' which is due to transpiration is evident.

DISCUSSION.

It has been shown by these experiments what many recent investigators have suspected, viz., that the physical thermal properties exhibited by leaf tissue provide an adequate means of dispersal for excess radiant energy.

Even though Clum found that transpiration, at best, was responsible for only two or three degrees of cooling, while Transeau (10) computed 45% of the energy available per acre to be used in this work of evaporation, these results are not at all irreconcilable. The latter calculated his results for an acre of corn, the same plant which Miller and Saunders, in over a thousand determinations, found did not differ materially in temperature from that of the air. Because such a large percentage of energy was used in transpiration, it does not mean that the latter function was the mechanism which prevented the overheating of the tissue. It simply means that the rate and intensity of the incident radiation was just the correct amount to be almost entirely absorbed by the vaporization which was taking place. Had the intensity of the radiation been materially increased we would find that the physical thermal properties of the tissue and not transpiration would

prevent overheating. In the latter case, although transpiration would probably be slightly increased, it would consume a much smaller percentage of the available energy than in the situation noted above. It is, therefore, quite impossible to calculate the relative importance of transpiration as a cooling agent by observing the percentage of the available energy which it consumes.

In all of these experiments the rate of temperature loss only was determined.

But $dQ_t/dt = d\theta_t/dt \times a$

where dQ_t/dt is the rate of heat loss in calories at time 't'

$d\theta_t/dt$ is the rate of temperature loss in degrees at time 't'

a is a constant whose value is the product of the mass and specific heat of the tissue concerned.

If we wish to compare the rates of temperature loss of two types of tissues of known cooling rates, we have

$$\frac{d\theta'_t/dt}{d\theta_t/dt} = \frac{-K'\theta_t}{-K\theta_t} = \frac{K'}{K}$$

and the ratio becomes that of the cooling constants.

Cereus $K = .05$

Bryophyllum $K = .38$

Liriodendron $K = 2.10$

Thus *Bryophyllum* cools 7.6 times as fast as *Cereus*.

Moreover *Liriodendron* cools 5.5 times as rapidly as *Bryophyllum* and 42 times as fast as *Cereus*.

As an example of how the rate of temperature loss may be used to determine the absolute emissivity the following calculations for *Liriodendron tulipifera* were made.

$$K = 2.1$$

$$\text{Mass of Leaf} = .79 \text{ gms.}$$

$$\begin{aligned} \text{Total area of leaf} &= 70. \text{ sq. cms.} \times 2 \\ &= 140. \text{ sq. cms.} \end{aligned}$$

Using Brown and Escombe's value of .879 for the specific heat of the leaf, we are able to find the absolute emissivity per sq. cm. per unit temperature difference.

Thus

$$\frac{2.1 \times .79 \times .879}{140} = .010 \text{ cal. per sq. cm. per min. per degree temperature difference.}$$

Brown and Wilson's calculations for this same species by the differential transpiration method gave the result .012 cal. per sq. cm. per min. per degree difference in temperature.

We can now calculate at what temperature the leaf would come into thermal equilibrium with its surroundings under the same still air conditions as were used to find 'K.'

The equilibrium temperature when the leaf is receiving on one surface incident radiation at the rate of .5 cal. per sq. cm. per minute and transpiring at the normal rate can be computed. Assuming the coefficient of absorption of the leaf to be .65, the equilibrium temperature would be.

$$\frac{.65 \times .5}{2 \times .010} = 16.3 \text{ C. } ^\circ \text{ above air temperature.}$$

Clum, working with *Fuchsia speciosa*, *Phaseolus vulgaris*, *Brassica oleracea* and *Syringa vulgaris*, observed maximum temperatures to be 13° C. and 16° C. for the open field and greenhouse, respectively.

One fact appeared during the course of the experiments which appeared difficult to explain. At 3 C. ° temperature difference the value of 'K' fell off rather sharply and consistently in *Liriodendron* and only slightly less marked in *Bryophyllum*.

The average value of 'K' for *Liriodendron* over 13 trials was 1.8 as against 2.1 for temperature differences greater than 3 C. ° In *Bryophyllum*, for eight trials, the drop in emissivity was noted from .38 to .35. No such drop appeared in four trials with *Cereus*.

There are two possible explanations:

1. A greater proportion of temperature loss is due to transpiration under a 3 C. ° temperature difference and less to the physical properties of the leaf. The former method of energy dispersal disposes of the heat less rapidly than the latter, with a consequent drop in the rate of temperature loss, and also in 'K.'

2. At lower temperature differences under still air conditions the removal of air from around the cooling tissue by convection currents is much less rapid and a decreased rate of cooling results.

SUMMARY.

1. Thermal emissivity and not transpiration is the agent which prevents overheating of plant tissue.

2. The proportion of available energy absorbed in transpiration gives no indication of its cooling value.
3. For temperature differences greater than 3 C.° the rate of cooling of a plant tissue is a linear function of the temperature difference between the leaf and air, under still air conditions.
4. The effect of desiccation is to increase the emissivity of the tissue.
5. A method is described for finding the thermal emissivity of the tissue by observing its rate of cooling under known conditions.
6. The rates of temperature loss and constant 'K' have been calculated for *Liriodendron tulipifera*, *Bryophyllum calycinum*, *Mesembryanthemum crystallinum*, *Echeveria weinbergia*, and *Cereus*.
7. A comparison of the constants of proportionality between rates of cooling for any two plants gives a comparison of the rates themselves. Thus the plants can be grouped according to their respective emissivities.
8. The thermal emissivity of *Liriodendron tulipifera* was determined and compared to the value found by Brown and Wilson for this species. The result was 17% less than that of Brown and Wilson.
9. A formula was derived for finding temperature of a tissue of known emissivity and initial temperature, after the interval of any number of minutes. Conversely the length of time required for the tissue to fall in temperature any number of degrees can also be determined from the same formula.
10. The presence of vaseline upon the surface of a plant tissue decreases, *per se*, the emissivity of that surface.

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